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Report

TASK REPORT

on

PRELIMINARY ASSESSMENT OF INDUSTRIAL NEEDS FOR ADVANCED OCEAN TECHNOLOGY
(Report No. BCL-OA-TFR-79-4)

A. G. Mourad, K. M. Maher, J. E. Balon,
A. G. Coyle, and J. A. Henkener

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BATTELLE
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

FOREWORD

This study was performed by Battelle's Columbus Laboratories (BCL) as Task No. 35 under Contract No. NASw-2800, for the NASA Office of Space and Terrestrial Applications (OSTA). Dr. A. C. Robinson is the Battelle Project Manager and Ms. Sandra Morey is the NASA Contract Monitor. The Task Leader for this study is A. George Mourad. Other BCL participants are: Jo Ellen Balon, Kathy Maher, Art Coyle and Jerry Henkener. The NASA/OSTA Technical Monitor is Mr. Nelson Milder.

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Dr. Subrata Chakrabarti, Manager of Marine Research, Chicago Bridge and Iron, Chicago, IL

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* Mr. Ray Kauffman - Chief Engineer, Deepsea Ventures, Gloucester, VA

Mr. Marne Dubs - Director, Ocean Resources Department, Kennecott, NY

Mr. Atle Steen - Kennecott Exploration Inc., San Diego, CA

Mr. John Kiefner - Senior Researcher, Battelle, Houston, TX

Mr. Jeff Simmons - Vice-President, United Gas Pipeline, Houston, TX

** Dr. W. S. Gaither - Dean, Oceanography, Univ. of Delaware

Dr. G. I. Shiller - Sr. Marine Geologist, Nekton, Inc., San Diego, CA

Dr. I. S. Blumenthal - The Rand Corporation, Santa Monica, CA

Mr. G. K. Morrison - Application Engineering Manager, Neil Brown Instrument Systems, Inc., Cataumet, MA

Mr. Tom Lovorn - Lockheed Ocean Laboratory, San Diego, CA

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Capt. J. Mackenzie - Consultant, San Diego, CA

Dr. J. R. Beyster - Science Applications, Inc., LaJolla, CA

Mr. Jim Edberg - Manager, Jet Propulsion Laboratory, Pasadena, CA

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* Requested copy of final report.

** Requested copy of final report and use of his offshore reports as references.

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A. J. Coyle and J. A. Henkener

SUMMARY

This report presents a quick-look review of selected ocean industries for the purpose of providing NASA OSTA with an assessment of technology needs and market potential. The objective of this study is to identify the appropriate ocean industries, their size, growth potential, needs and problem areas and the technology presently used as well as the suppliers of such technology. Only certain industries were selected and discussed which have problems related to the subocean surface, including subbottom. For each industry selected, we tried to present (1) a brief description, including size and market potential, (2) state of the art in technology, (3) names of major companies, (4) outline problem areas as have been reported in the literature or developed through telephone interviews, and (5) examples of selected key problem areas that are amenable to advanced technology solutions.

Except for deep ocean mining interests and those of the military, most of the ocean industry activities requiring advanced technologies are concentrated within 200 miles offshore. There are many factors affecting the growth of the offshore industry. These include (1) economics, (2) policy, and (3) technology. In the mature industries such as the petrochemical industry, the economic and policy factors dominate future expansion and decisions. Conversely, technology is going to be essential for the development of deep ocean mining resources, since it is a fairly new industry. However, the decision to commence mining operations might not be purely economic; rather, it may be dictated by political considerations. The ocean industries selected and treated in this report are summarized in Table 1, which also gives their present size and growth potential. A brief summary of each selected industry is given next.

TABLE 1. SIZE AND GROWTH PROJECTIONS FOR OCEAN INDUSTRIES

Industry Segments	Present Size, million dollars per year	Growth/Future Size Projection, million dollars
Deep Ocean Mining	Experimental stage	1,600-4,000 cumulative by year 2000 [investment in ocean vessels/equipment/ facilities]
Petrochemical Industry	20,000-25,000 (1979)	60,000-70,000 per year by year 1990
- U.S. Portion (15-20%)	3,000-5,000 (1979)	10,000+ per year by year 1990 20,000+ per year by year 2000
(1) Offshore Exploration/Development Worldwide	35,000 (1965-1975)	155,000 cumulative 1975-1985
- U.S. Portion	Data incomplete	90,000 cumulative 1975-1985
(2) Offshore Completion/Production Segment		
- Offshore Drilling	13,000 (1979)	Data incomplete
- Subsea Completions	65 (1977)	250 per year by year 1982
Ocean Energy Conversion (mostly OTEC)	35 (DOE funding in FY1978)	Depends on government funding and entrance of firms into market
Ocean Surveying		
(1) Seismic for Petroleum Exploration	210 (1978)	Data incomplete
- U.S. Portion	77	
(2) Gravity/Magnetic		
- U.S. Portion for Petroleum Exploration	3.4 (1978; 67% more than 1977)	Data incomplete
- U.S. Portion for Other Exploration (minerals, geothermal, etc.)	3.0 (1978)	Data incomplete
Inspection/Diving Services	60-70 (1979)	Data incomplete

Deep Ocean Mining Industry

Deep ocean mining is a fairly new industry concerned with mining manganese nodules from the ocean floor. Manganese is of extreme importance to the U.S. steel industry, which imports about 98 percent of its needs. There are four major international consortia involved in testing and evaluating the feasibility of mining these nodules. The factors affecting ocean mining operations include (1) technology, (2) fiscal control (prices of metals), (3) market control (political -- ability to obtain needed resources on world markets), and (4) economic. Although technology will play a major role, political factors may be most significant in the decision on commencing commercial operations.

The general consensus of opinion is that present technology is adequate to meet the needs of testing and operational feasibility of deep sea mining, but that there are potential problems, especially relating to equipment reliability and design life which may become more apparent during extended operations. This industry develops most of its mining technology and draws upon the capabilities of several small technology-oriented companies for specific instrumentations involved in bottom surveys and positioning. Accurate position/navigation/tracking information is required for surveying the mine sites and development of several types of maps required for operation such as bathymetric, assay, ore, and geotechnic maps. Major problems identified include establishing a stable legal framework and necessary legislation for mining in international waters, improving the efficiency of seafloor topography/obstruction mapping, improving the capability of positioning and tracking bottom equipment, developing high risk, long range technological concepts such as subsea power, improving maintenance, material testing and component reliability and developing versatile equipment vehicles with plug-in modules.

Petrochemical Industry

By far, the petrochemical industry is the largest of all the offshore industries, as can be seen in Table 1. This industry is considered mature and highly developed in terms of technology and even profitability. The petrochemical industry is discussed next in terms of exploration and drilling; platforms, production and completion; and pipelines as a transportation medium for discovered oil and gas.

Exploration and Drilling

Explorations for offshore oil and gas involve the use of various geophysical methods such as seismic, gravimetric and magnetic. These methods provide information on the geological structures and identify favorable formations for oil and gas deposits. However, no matter how strong the geophysical evidence of oil and gas may be, the only proof is through drilling. Seismic surveys are perhaps the most significant of all other geophysical methods used, as shown by the large expenditures (see Table 1) in comparison with other techniques. Seismic technology is highly developed, and more detailed information is provided in the section on ocean bottom surveys. The major areas of challenge in future operations of the offshore petrochemical industry are in the field development and production rather than in exploration or drilling. Drilling has already been attempted at depths of about 1500 meters. Future drilling techniques up to 3000-meter depths are being contemplated. The many large companies involved in drilling include Brown and Root, Comex, Fluor, Global Marine, J. Ray McDermott, Santa Fe and several of the major oil companies. Examples of problem areas that are amenable to high technology solution include obtaining more accurate subbottom data describing the geological formations; improving data collection system resolutions, and computer processing; and developing comparison techniques with core samples.

Offshore Platforms, Oil Completion and Production

About 95 percent of the offshore platforms are steel. New platform types such as gravity (concrete), articulate and tension leg are in the experimental stage. The cost of platforms ranges from less than $1 million for the small four-well platform to as high as $800 million for large complexes in the North Sea that could have as many as 60 wells. Most of the present day platforms are production types and are fixed to the ocean floor. Therefore, knowledge of the bottom conditions is essential. Economic feasibility studies indicate that a maximum depth of 180 meters is possible for these platforms. However, new concepts in design show that it is possible to build structures at even 600 meters.

The most promising development for deep water applications is subsea completion, which is also competitive in shallow waters. Subsea completion means the establishment of production from a well while leaving the wellhead and all other primary controls either exposed to the water or fully enclosed in a capsule on the ocean floor. An important advantage of subsea completion is that oil fields can be produced in deep waters where erection of platforms is not economical. Expenditures of subsea completion are expected to reach about $250 million a year by 1982. Problem areas include lack of data on wave spectra, soil properties and slope stability, liquefaction and seismic faults, maintenance of structures, design of and protection of equipment, particularly in arctic areas, data transmission from remote control of wells and deep-water mooring. Examples of key problems amenable to high technology solution include (1) earthquake measurement programs including instrumentation and data collection and dissemination, (2) subsea completion (location, operating status, diagnosis, and the transmission and processing of this vast amount of data to the surface), and (3) soil structure interaction under cyclic and dynamic loadings.

Offshore Pipelines

The offshore oil and gas pipeline industry consists of three major segments: the natural gas pipeline companies and joint ventures which design and operate pipelines, the offshore construction contractors, which lay pipelines, and ocean engineering contractors, which provide inspection and repair services. This industry has kept pace with the offshore production trends of the 1970's including the trends toward deeper waters and more hostile environments. The Gulf of Mexico continues to be an active area. Installations at depths of 300 meters have been accomplished and 1.2-m (48-in.) pipeline diameters have been set. Installation at 600-meter depths is being designed for offshore Italy. Rapid technological advances have been made, as witnessed by the development of new submersible pipelaying ships. Research is in progress to develop variable density, lighter weight pipes that can be installed in deeper water. Problem areas are associated with deeper water and severe climatic conditions affecting design optimization and hazard assessment. Industry needs data on the boundary layer (soil stability, mudslide, shear strength, etc.), and instruments to measure internal corrosion; additionally, it needs to develop innovative pipelaying techniques and long-distance pipelaying design, determine the feasibility of pipeline corridors, and determine geotechnical properties and the behavior of marine soils.

Ocean Energy Conversion

The process of ocean thermal energy conversion depends on the temperature differential between low-temperature bottom waters and high-temperature surface waters for employment of heat engines to extract energy from the oceans. Since this concept requires a huge amount of research, development and capital investment, industry has been reluctant to invest any large sums of money in this area. Therefore, the U.S. Government has been financing ($35 million in FY78) practically all of

the prototype and critical component work. While technical feasibility has been demonstrated, economic feasibility is questionable. Currently a 50-kw "mini-OTEC", funded by DOE, has been deployed off Hawaii and a 1-Mw version is scheduled for operation in 1979. Other ocean energy conversion devices such as those using wave energy are being evaluated. There are still several critical problem areas remaining in this technology. These include heat exchanger problems of thermal design and biofouling, ocean engineering problems of platform design, mooring, power cable, and cold water pipes.

Supporting Industries

Supporting offshore industries are an aggregate of many small industries which are intensive in high technology and often serve both government and industry.

Ocean Bottom Surveys

Ocean bottom survey is basically a service industry composed of three segments: the marine geophysical surveying service contractors, the equipment suppliers, and the vessel suppliers. This industry is a complex one composed of many highly specialized firms as well as subsidiaries of larger companies such as Texas Instruments, Litton, and Raytheon. Basic services supplied by ocean bottom surveys include (1) geophysical surveying, (2) hydrographic/bathymetric mapping, and (3) core sampling/soil analysis. Prerequisite to these survey activities is accurate position information on the ocean surface, subsurface, and bottom. Real-time integrated position/navigation systems are required. Ocean bottom exploratory activities are undertaken to (1) locate geological formations which are potential oil and gas reservoirs, (2) determine topography of the sea floor for mapping/charting of navigation hazards, and (3) define the properties of the ocean bottom soil that provides the foundation for establishing large structures and dumping sites and laying cables and

pipelines. Recent technological advances include 3-D scanning, color graphic displays, improved resolution and accuracy and a new generation of minicomputer data processing systems.

The geophysical industry is quite sophisticated in the development of advanced techniques and instrumentation and in signal processing. Seismic surveys use multichannel reflection techniques (48, 96 and even higher channels). The increased number of channels and detector spacing are employed successfully to provide redundancy, cancel random noise and to discriminate against horizontal waves. Vibratory techniques have been developed on land and are being applied at sea which can generate a known signal (linearly swept frequency like a chirp). Signal processing is quite sophisticated. All recordings are made digitally to maintain the dynamic range and also for ease in filtering and computer processing.

Bathymetric/hydrographic techniques used today in ocean bottom topographic surveys produce levels of accuracy and resolution that would have been unthinkable only a few years ago. Both surface vessels and submersibles are used. Submersibles are in great demand because increased accuracy and resolution require that survey sensors be located as close as possible to the ocean floor.

Offshore structures such as drilling and production platforms, pipelines, cables, subsea completion, waste disposal outfalls and structures to support navigation aids must be supported on the ocean floor; thus, the need for better information on soil. Core samples are used to determine soil properties. A need exists for a better understanding of the geotechnical properties and behavior of marine soils and of the interaction of soil with structures.

High technology is clearly required for electronic equipment used for subsea mapping. The industry now demands on-site processing of every element of data that has been collected. Advanced sensors are available for detailed bathymetry which, when positioned 2 meters above the seabed, produce myriad details as a result of their capability for high resolution. Used in conjunction with shallow coring techniques and sensors for subbottom profiling, they enable charts of unsurpassed detail to be produced.

The general problem areas are associated with ocean bottom mapping, positioning/navigation/tracking, seafloor characteristics and sampling techniques and collection of oceanographic, meteorological and ice-related data for the design of structures and facilities. Systematic mapping of the continental shelf is required. However, this is the responsibility of the Federal Government, which needs to establish map specifications, policy and plans suitable for various ocean users, whether governmental or civil.

Since the ocean bottom survey is a service industry, the technological problems involved are those that are affecting the primary marine industries (petrochemical, mining, pipeline and cable laying). Thus, although improvements in technology are supplied through R&D efforts of this service industry, the demand (i.e., need) for technological improvements is generated in the primary industries, which pay the service industry to supply needed technology and technical expertise. For this reason, the high technology solutions listed below are discussed within the industry subsection* to which they most apply:

Needed Technological Improvements	Industry
Soil-Structure Interaction under Cyclic and Dynamic Loadings	* Oil Completion/ Production - Offshore Pipeline
Definitive Studies on Geotechnical Properties/ Behavior of Marine Soils	* Offshore Pipeline - Oil Completion/ Production - Deepsea Mining
Typical Area Research and Survey Specifications for Offshore Corridors/Zones	* Offshore Pipeline
Earthquake Measurement Programs	* Offshore Platforms - Oil Completion/ Production

Underwater Transportation, Data Collection and Work Systems

Underwater transportation has been limited to small two-, three- and four-man submersibles. These submersibles have been used for surveying pipeline routes, pipelaying and trenching, inspection of platform sites, and construction operations. Most of them have limited duration and operate at depths of 300 to 600 meters. Several kinds of remotely controlled vehicles (RCVs) and towed vehicles (manned and unmanned) have been developed and used in various underwater surveys and operations. These are equipped with lighting, cameras, television, sonar, manipulators, etc.

The rapid growth in undersea vehicles which followed development of the North Sea oil and gas discoveries of the late sixties and early seventies continues. While the diver still conducts most underwater activities, his role is decreasing dramatically as operations move into deep waters. The number of operational RCVs increased from 39 to 53 and that of manned submersibles decreased by six during 1978. The problem areas include reliability, maintenance, bottom navigation and location, design of work system packages for the limited payload, and stability of these vehicles.

Inspection and Diving Services

Inspection and diving services have enjoyed rapid growth and formed the cutting edge of the state of the art in diving, diving physiology, underwater tools, underwater cutting and joining, inspection instruments and petroleum engineering. Diving costs increase with depth, and beyond 200-meter depths diving becomes uneconomical. Such costs forced the petrochemical industry to design systems that minimize the need for divers. This trend has led to the development of subsea wellhead completion and production, which also caused increased use of the RCVs. These vehicles are taking over the role of divers in many offshore applications, such as survey and inspection of pipeline routes, inspection for leaks and deterioration of pipelines and platform structures. However,

most of the RCVs use cables to provide power, and to transmit data and information from and to the control station. These cables limit the usefulness of these vehicles for inspection of offshore towers because of cable fouling.

The state of the art in diving in water depths over 200 meters is in its infancy. Some demonstration dives have been made in about 315 meters; and simulated dives in hyperbaric chambers have provided data that could make diving possible at about 450 meters. However, the long decompression periods and the economics will make such dives unreasonable. RCVs, manned and unmanned submersibles, diving bells and one-atmosphere working systems are being developed to replace divers in deep water. Some of the problem areas include the physiology of bone (e.g., necrosis), the high cost of mixed-gas and saturated diving, nondestructive testing and inspection of structures, and development of RCVs without cables and means for data transmission to the ocean surface.

RECOMMENDATIONS

On the basis of the results of this preliminary assessment of the ocean industries and their needs for advanced technology, and in order for NASA to achieve an effective deep ocean technology transfer program, we recommend the following initiatives:

(1) Conduct a similar assessment of the involvement of government and academic institutions in national and international ocean programs for identification of problem areas and determination of their needs for advanced technology.

(2) Analyze selected problem areas common to industry, academia and government that are amenable to advanced technology solution; then match these needs against applicable NASA space technology.

(3) Conduct a detailed market/user requirements analysis for selected technologies including the determination of specific needs, industrial R&D capabilities and technology suppliers.

INTRODUCTION

Background

As man seeks to solve the multiplying energy and environmental problems confronting him, he is turning more and more to such new frontiers as the sea. The last two decades have witnessed a considerable increase in the search for oil and gas in offshore areas on the continental shelves and slopes of the world's oceans. As the technical feasibility of deep ocean mining is continually demonstrated and upgraded, extraction of these additional resources becomes increasingly attractive. Other uses of the seas for food, and the development of ocean resources for transportation, recreation and other activities, also encourage the expansion of this important frontier.

Although various ocean activities and developments are currently prosperous and thriving, over the years, ocean-related budgets and forecasts have fluctuated enormously. In several time periods since the 1950's, big industrial concerns such as the aerospace industry have become involved in various ocean activities in the hope of cashing in on the exploration of man's last frontier, the innerspace. Many of these companies, however, were heavily dependent on government funding for their survival. The Vietnam War and other political consequences took their toll on many of these companies, with the result that they dismantled their ocean activities as quickly as they had started them. The major remaining industry to which many billions of investment dollars and technological development can be attributed is the offshore petrochemical industry. As time goes on, the growth of various ocean industries will continue to be influenced, to a great extent, by the rate of growth and health of the offshore oil and gas industry. According to Nathan Associates[(1)*], this industry represents the largest single economic

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*Superscript numbers denote references, which are at the end of the report.

activity in the world's oceans. The value to the United States alone was estimated at $3.2 billion in 1973, with projections of $18.8 billion per year (1973 $) by the year 2000. Unfortunately, there are no readily available recent data on the involvement of the offshore industry in terms of revenue, profit or investment.

The offshore oil and gas industry is a highly developed one from the standpoint of advanced technology, particularly in exploration techniques, drilling and platform construction and production operations. This industry will probably still lead in future advancement. For example, drilling techniques are being pursued for 1000 to 3000-meter depths. The use of subsea completion for oil and gas production at such depths is being contemplated.

Over the past decade, many small industries have blossomed in support of offshore oil and gas development. These supporting industries are engaged in many activities such as surveying, positioning, navigation, communication, engineering, diving, instrument and equipment development and environmental studies. They constitute the hundreds of aggregate individual small companies that are specialized in certain technological activities. Many of them are highly intensive in high technology, particularly in computerization and on-line data handling. These companies often serve other ocean industries as well as various government activities in the ocean. As a result, the separation of income from government and industry is not readily available.

Except for deep ocean mining interests and those of the military, most of the ocean activities requiring advanced technologies are concentrated within the 200-mile coastal zone. There are many factors affecting the growth of the offshore industry. These include (1) economics, (2) policy and (3) technology. In the mature industries such as petrochemicals, the economic and policy factors dominate future expansion and decisions. Conversely, since it is a new industry, technology is going to be essential for the development of deep ocean mining resources. However, the decision to commence mining operations might not be purely economic. Rather it may be

dictated by political considerations; e.g., the inability to obtain essential elements such as manganese from exporting nations. In general, the economic potential of ocean resources and the degree of risk involved will determine the future success and growth of the ocean mining industry.

Recent political situations, increased regulation and environmental conditions are playing a major negative role in increasing the economic risks of the ocean industry. In recent years, the economic risks have increased tremendously, particularly because of the various ocean policies and regulations imposed on the industry. Changes need to be made and cooperation between government and industry is essential, not only to reduce the economic risks, but also to make the U.S. ocean industry more viable and competitive with that of the rest of the world.

Scope

This report represents a quick-look review of selected ocean industries for the purpose of providing NASA OSTA with an assessment of technology needs and market potential. OSTA is involved in the demonstration and transfer of advanced technology that has applications for deep ocean activities. This task represents a first step in an overall NASA effort aimed at determining a role, if any, for the applications of NASA's advanced technology to the solution of problems associated with deep ocean activities. Specifically of concern are the following:

(1) Identification of needs for problems of deep ocean technology

(2) Identification of relevant NASA technologies

(3) Survey of users and their comparable capabilities

(4) Review of NASA's past efforts related to such activities

(5) Recommendation of a plan of action.

The objective of this study is to identify the appropriate ocean industries, their needs and problem areas and the technology presently used as well as the suppliers of such technology. In addition, information is required on the size and growth of such industries

and their needs for use of improved technology. The general approach used to achieving these objectives is to:

- Review available literature and sources of information
- Define and group appropriate ocean industries and determine their size and market growth potential
- Define problem areas
- Conduct telephone interviews with selected industry representatives to assess their advanced technology needs. A telephone interview format was developed and used for discussion.

At the outset of this study it became obvious that several workshops attended by many industry representatives had been conducted and reports prepared wherein a number of the deep-ocean problem areas were outlined. Several of these problems have been extracted and reported herein. In most cases, the problem areas reported in this document were not conceived as a result of this study, but rather resulted from a consensus of opinion among industry representatives attending various workshops convened for such purposes.

For each industry selected, we tried to present (1) a brief description, including size and market potential, (2) state of the art in technology, (3) names of major companies, (4) outline problem areas as have been reported in the literature or developed through telephone interviews, and (5) examples of selected key problem areas that are amenable to advanced technology solutions. No attempt has been made to evaluate these problems or the technology to be utilized for their solution.

Because of the time constraints and the primary interest in defining industry problem areas related to the subocean surface, including subbottom, several industries were excluded from treatment in this report. Examples of such industries that were briefly reviewed but not treated are: shipping, tankers, ports and facilities, estuarines and coastal processes, fisheries, desalinization, food extraction, pollution, regulatory and recreation. Industries that are involved in collecting ocean surface environmental data such as on waves, winds, sea surface temperature, currents and tides or with communications were excluded since NASA is already involved in the development and launch of satellites for monitoring and measuring these phenomena.

DEEP OCEAN MINING INDUSTRY

Industry Description

In the 1960's, it was discovered that the deep seabed areas of the oceans contain an abundance of mineral resources, known as manganese nodules, which contain commercially significant quantities of nickel, copper and cobalt in addition to high concentrations of manganese, zinc and molybdenum. In particular, the most potential has been found in an area of the Pacific between Hawaii and Mexico at depths of 3600 to 5800 meters. Four international consortia have been formed to assess the viability of commercial nodule mining operations. Seven U.S. firms are members of these consortia as shown below:

Consortium:	Kennecott
Operator:	Kennecott Exploration, Inc.
Members:	Mitsoubishi Corp. (Japan)
	Noranda Mines Ltd. (Canada)
	Rio Tinto Zinc (U.K.)
	Consolidated Goldfields (U.K.)
	Kennecott Copper Corp. (U.S.)

Consortium:	Ocean Mining Associates
Operator:	Deepsea Ventures
Members:	U.S. Steel (U.S.)
	Sun Company, Inc. (U.S.)
	Union Minere (Belgium)

Consortium:	Ocean Management, Inc.
Operator:	INCO
Members:	INCO United State, Inc. (U.S.)
	AMR (German)
	DOMCO (Japan)
	Sedco, Inc. (U.S.)

Consortium:	Ocean Minerals
Operator:	Ocean Minerals Company
Members:	Lockheed Aircraft Company (U.S.)
	Billiton Minerals International
	BOS Kalis Westminiski (Netherlands)
	AMOCO Minerals Company (U.S.)

Each of these consortia has invested tens of millions of dollars in research programs to develop and test the technology to locate, mine, and process the nodules. If and when commercial operations commence, each consortium would invest approximately $1 billion (1979 dollars)[2], for a total of $4 billion for the four existing consortia. However, land-based processing plant investment would account for more than 50 percent of the commercial investment.[3] Assuming 40 percent of potential commercial investment would be for ocean technology, one can estimate the potential commercial investment in ocean equipment and vessels at approximately $1.6 billion (1979 dollars). As an upper limit, it is assumed that more firms would enter the market and potential capital investment for commercial ocean mining by the year 2000 could amount to $10 billion (1979 dollars).* The portion of this going to ocean vessels and equipment would then amount to $4 billion (1979 dollars).

Present ocean mining industry expenditures are extensive and, even in a good investment climate, it is too much to expect any one company to pay the billions of dollars required to extract these resources. Three factors are needed for developing a viable ocean industry.[5] These are:

(1) Market control: The ability to obtain needed resources at any time. For example, manganese is essential for the steel industry. The U.S. imports about 98 percent of its manganese needs. Thus, any extended interruption of supplies could result in a shutdown of the steel industry.

(2) Fiscal control: Fluctuating price cycles of minerals restrict the industry's capability in the areas of analyzing technical and economic feasibility of future mining operations.

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* See Reference (4), which estimated total investment by the year 2000 at $9 billion in 1975 dollars (Vol. 1, p. 95) which approximates $12 billion in 1979 dollars. However, this estimate was based on commencement of commercial operations in the early 1980's which now seems too optimistic.

(3) Legislative control: Ocean mining requires large investment; thus, there is the need to minimize the risk and provide a healthy investment climate.

State of the Art

Since 1977, the deep ocean mining consortia have been testing prototype equipment in pilot mining tests. Three types of nodule-gathering systems tested include a mechanical bucket-line technology and two hydraulic systems (air lift system in which air is injected into pipes at depths of 1500 to 2500 meters, and submersible pump system where suction is provided by pumps installed in the pipes at a depth of approximately 1000 meters). A steerable (about 10° to 15°) gathering device may be tested soon by one consortium. It may also be possible, in the distant future, to develop a self-propelled gathering device which would differ radically from the vessel-propelled technologies described above. The latter, however, may require a major breakthrough in power supply system to make it feasible operationally.

In the area of exploration, advanced technology presently utilized includes: free-fall boomerang box corers, grabs and cameras; deep-towed instrument platforms with precision depth recorders, sub-bottom profilers, side-scan sonar, tv and stereo color photography. The deep ocean industry draws on the navigation and positioning technology of the offshore oil industry, but has unique problems in the dynamic positioning requirements associated with vessel-towed mining systems. The industry employs integrated satellite and bottom-mounted transponder navigation systems where the industry has improved the reliability and spare parts requirements of such systems.[5] Other systems being considered include multibeam hull-mounted sonar systems.[6] Present seafloor equipment surface vessel referencing techniques may be inadequate in resolution

(telephone conversation: "need to know position of mining equipment on seafloor within a few feet"). Actually, ocean bottom positioning in the form of tracking the equipment on or near the ocean floor is the most important. Accuracy of the order of 5 to 10 meters horizontally and vertically is now considered a requirement in order to avoid hazards.[6] A detailed survey of the mining site is required prior to operations in order to identify resources, and importantly, hazards.[5,6] Pipe leeway is of the order of 100 meters, where operators can make the necessary adjustment once the hazard (previously mapped) is seen by the forward and/or down-looking sonars ahead of the collector. Present capabilities for collector positioning are of the order of 150 meters, although surface positions can be obtained to much higher accuracy.[6]

Ocean mining operations have requirements for several types of maps[5] such as:

- Bathymetric maps to record changes in topography and general terrain
- Ore maps to determine the deposit concentration
- Assay maps to ascertain the chemical composition of the resources
- Geotechnic maps to describe the bottom soil conditions and whether they could support the mining equipment.

Above all, ocean minings need the exploration data to produce a functional map(s) on the basis of which planning and operational decisions can be made

The general concensus of opinion is that present technology is adequate to meet the needs of commercial deep sea mining testing and feasibility operations, but that potential problems, especially relating to equipment reliability and design life, will become apparent in actual commercial operations with the associated environmental stresses (corrosion, abrasion, pressure, and long-term stress effect on pipes). The industry in general develops its own mining technology and draws

upon the capabilities of several "small" technology-oriented companies for specific instrumentations involved with bottom surveys and positioning.

Problem Areas

The major problem that is preventing commencement of commercial operations is the lack of a stable legal framework for mining in international waters. The United Nations Law of the Sea Conference has been unable to reach agreement on such a framework and it is unlikely that commercial investment will be made until agreement is reached, due to the investment risk involved. Interim U.S. legislation (i.e., Deep Seabed Mining Act) has been considered, but due to the international makeup of the industry consortia, such legislation probably would not adequately insure commercial investment. Previous estimates placing commencement of commercial operations between 1981 and 1984 were based on the assumption that an international agreement would have been reached in the Law of the Sea Conference. It is now more conservatively estimated that commercial operations will be delayed for a decade, possibly until 1990 at the earliest (telephone conversation).

Other Problem Areas

- Inadequate oceanographic/meterological data (wind, wave, current, etc.) and, in particular, storms.
- Improve efficiency (speed, accuracy, cost) of seafloor topography/obstruction mapping; advance data processing and display.
- Improve positioning/reference and tracking technology (seafloor equipment relative to surface vessel). Bottom transponders have limited applications due to limited field of view.
- Develop environmental guidelines for deep ocean mining operations (especially related to waste disposal, discharge or accidental spillage of caustic reagents, and disturbance of seafloor ecology). This is important

if the U.S. is the only nation having jurisdiction over the mining rights. Other countries may not be as environmentally conscious as the United States. Besides, mining systems have already been developed where environmental guidelines are perhaps five years late. One cannot expect the industry to rebuild their systems now for whatever guidelines might evolve in the future.

- Develop high risk, long-range technological concepts such as subsea power and maintenance systems.
- Materials testing and component reliability for long pipes (mechanical and structural) under stressful deep ocean environmental conditions. Some industry members feel that they must go ahead with operational evaluation as soon as possible even at the risk of not considering all the theoretical potential pitfalls. They feel that empirically derived guidelines based on operational statistics are more valuable.
- Develop versatile equipment and vehicles with plug-in modules that can apply to the solution of various problems even in different industries. Thus, the costs can be shared by other groups.

PETROCHEMICAL INDUSTRY

Oil Exploration and Drilling

Industry Description

Oil exploration using seismic and gravimetric techniques is more easily accomplished offshore than on land. However, it is more difficult to find oil seeps and sniff for hydrocarbons at sea because of greater dilution and the washing away of seepage. Seismic surveys are conducted by firing explosive charges, including air-gas mixtures, to create shock waves which pass through the ocean subbottom; the reflected waves are then picked up by transducers and recorded. These recordings provide information on the geology of the ocean subbottom and the possible location of oil and gas deposits. Gravimetric surveys identify changes in the density of the earth, such as the occurrence of salt domes, that have signaled a number of stratigraphic traps for holding oil deposits. More detailed information is given on geophysical

surveys, including seismic, in the section on bottom surveys. However, no matter how strong the evidence of oil or gas may be, the only proof is the drillers bit used in exploratory drilling or "wildcatting". A new technique using geochemistry in stratigraphic test wells is providing more acurate survey results.

Worldwide offshore oil and gas expenditures in this industry are estimated for 1979 to be about $20-25 billion and by late 1980 will be $60-70 billion per year, which includes exploration, new construction, fixed platforms and operation costs. About 15 to 20 percent of this expenditure is in U.S. waters. It is also expected that expenditures in the U.S. will increase even more than the world rate. In the past 10 years, expenditures have increased tenfold, so the $60-70 billion may be a conservative estimate[7].

There were over 600 exploratory and drill rigs working offshore in July 1978, of which 376 units were operating in U.S. waters In 1977, over 124 tracts were leased in the Gulf of Mexico at a cost to the industry of $1.17 billion. The cost of a self-propelled drillship ranges from $30-50 million. The average cost of a jacking unit is about $16 million in 1977 dollars. The cost of a fixed platform rig package ranges between $5 million and $9 million. According to the Chase Manhattan Bank, a total of $35 billion was spent in offshore exploration and development during the 10-year period 1965-1975[8]. The bank further estimated, for the years 1975-1985, and applying a 10 percent inflation rate, that worldwide offshore expenditures will be $155 billion, of which $90 billion will be expended in U.S. waters.

State of the Art

The major area of challenge in the future operations of the offshore oil and gas industry is in field development and production, rather than in exploration or drilling.[9] The drillship "Discoverer Seven Seas" spudded a well in the Atlantic some 200 miles off Newfoundland in almost 1500 meters of water in April 1979. This ship drilled five wildcats in waters deeper than 900 meters in the previous 18 months.[10] This capability contrasts with the limitations on pipelaying and ocean

bottom (subsea) production, although these supporting technologies are being developed rapidly.[11] Exploration and drilling in Arctic regions, especially regions under ice or near areas subject to deep-bottom scour by ice masses, not to mention icebergs, is not only difficult technologically, but also extremely expensive.

Company Names

The number of companies engaged in this industry is large; however, some of the larger companies involved in pushing the state of the art are: Brown & Root, Comex, Fluor, Global Marine, Lockheed (LPS), J. Ray McDermott, Santa Fe Engineering Services, Chicago Bridge and Iron, and others. In addition to the above, there are numbers of shipyards, diving companies, well service companies, and of course the oil, gas and chemical companies, such as Shell, Exxon, Gulf, Getty and others, that invest billions per year in this industry.

Problem Areas

- Holding positions in deep water where mooring cables cannot be used. This is especially critical when launching heavy equipment.
- Obtaining a real-time down-hole data to determine in-situ conditions to prevent dangerous blowouts and to enhance drilling efficiency.
- Obtaining accurate subbottom data.
- Exploration and drilling under ice in arctic regions.

Examples of Key Problems Amenable to High Technology Solution

The obtaining of subbottom data that can accurately show the geological structure is a key problem area where improvements can save millions of dollars. Computer processing could be applied to subbottom data to improve the interpretation of the data. Improved data as well as comparisons with actual core samples will probably be required in addition to computer processing in order to significantly improve our ability to predict subbottom structure with its pockets of oil and gas.

Offshore Platforms

Industry Description

There are four types of basic platform designs used throughout the world: (1) steel, (2) gravity (concrete), (3) articulate, and (4) tension leg. About 95 percent of offshore platforms are steel. The other three types are more recent, and some of them are still experimental. The cost of platforms ranges from less than $1 million for the small four-well platforms to as high as $800 million for large complexes in the North Sea that would have as many as 60 wells.[12]

Since the first offshore platform was installed in 18 feet (5.5 meters) of water in the Gulf of Mexico in 1947, more than 3000 have been installed throughout the world. The first structure was a tower constructed of pipe supported on steel piling driven 104 feet (32 meters) into the Gulf floor. The well is still producing, with tanks and production equipment installed on the original platform.[13] Initially, land practice and equipment were adapted to the marine environment and transferred to platforms. Since then a gradual evolution of exploration, drilling and production techniques has resulted in systems and procedures better suited to the ocean environment.

This first platform supported a drilling derrick which drilled a "wildcat" or exploratory well. Most of the platforms installed today are production platforms from which as many as 60 wells can be drilled into proven fields. Wildcats and exploratory wells are usually drilled from drillships and other mobile structures such as "jackup" submersibles and semisubmersible drilling platforms. These platforms are normally towed into position, where the submersibles are ballasted with seawater to provide stability for the drilling operation: and the jackups use hydraulic rams to lower massive legs to the sea floor and jack the working platform above the surface of the ocean away from wave action.

Most of the production platforms throughout the world are constructed of steel pipe trusswork, and resemble that first offshore platform in design; huge steel piles are still used to anchor and support

them on the ocean floor. These platforms are used to slant drill a number of wells to reach various parts of the field being developed. The oil and gas is normally delivered to the platform, where it is cleaned, i.e., sand and water are removed and oil and gas are separated. In some cases, the gas is reinjected into the field to retain reservoir pressure. In the case of gas wells, various condensates and hydrates are removed to prevent freezing in gas lines in areas where throttling can lower gas temperatures. Well control and product equipment is located on the platform.

In recent years, massive reinforced concrete platforms have been designed and installed in the North Sea fields. These structures include the usual drilling, production and control equipment; in addition, a large number of tanks are built into the base structure, which can hold as much as a million barrels of oil in storage.

The most promising development for deep water application is the subsea completion, which is also competitive in shallow waters. The subsea completion looks like a Christmas tree on the ocean floor; the production, well control and maintenance equipment is included with this assembly or located nearby on the ocean floor. The wells are drilled by a surface platform, which directs the drillpipe through the subsea installation on the sea floor. Conductor lines connected to the christmas tree lead to a production unit (production means drawing of fluids and removing sand and water from the oil or gas). The produced oil can be led to the surface through a conductor to a floating reservoir, or pumped ashore. Therefore, fields can be developed without the use of platforms. Another advantage of subsea wellheads is that oil and gas can be produced earlier in a field development to provide cash flow, while hundreds of millions of dollars are invested in designing, constructing and installing platforms, storage reservoirs, pipelines and pumping facilities.

State of the Art

Development of offshore structures has been intensified in recent years with the discovery of fields in deeper waters. Achievements have been remarkable, even with fixed structures, which were considered too

uneconomical in waters greater than 180 meters. The Cognac platform is in 310 meters of water and, recently, J. Ray McDermott has evolved innovative ideas to greatly reduce the costs of a fixed platform to be installed in 285 meters of water.[11] In greater depths, various platforms such as the articulated column, the tethered buoyant platform and the tensioned buoyant platform and others are being considered. These developments coupled with subsea completions and production systems promise a challenge to many technologies. The present depth record for a fixed platform (Cognac) in the Gulf of Mexico raises the question of how well such structures would perform in the North Sea. Structures in arctic regions, especially those in ice-covered areas, require new concepts, as do those in areas prone to seismic activity and underwater mudslides.

Company Names

Sedco Inc., Houston
Bethlehem Steel Corp., Beaumont, Texas
Avondale Shipyards, Inc., New Orleans
Chicago Bridge and Iron, Chicago
J. Ray McDermott and Co., New Orleans
Brown & Root, Inc., Houston

Problem Areas

- Mooring in deep water, especially when moving heavy lifts to construct platforms
- Lack of soil properties and behavioral information
- Lack of data on slope stability, bottom liquefaction, and seismic faults
- Lack of data on wave spectra and the interaction of waves with structures
- Lack of design requirements for arctic regions to account for bottom scour by "landfast" ice, pressure ridges and icebergs

- Lack of long-term performance characteristics of reinforced concrete structures in the ocean environment
- Performance of large cable systems for tensioned (or tethered) buoyant platforms
- More knowledge on the behavior of sediment in river deltas for adequate structural designs
- Studies to determine the most effective means for field abandonment after the oil and gas are depleted
- More data in the area of anodic and cathodic protection of platforms and pipelines
- More data on ocean currents in deep water.

Examples of Key Problems Amenable to High Technology Solution

Earthquake Measurement Programs.[(4)] A need exists to improve earthquake engineering technology and its application to the design of offshore facilities. Therefore, a study is required to advance the capability of detecting the occurrence of earthquakes and to measure the resulting ground motions on the outer continental shelf. The effort should include development of improved instrumentation and the establishment and maintenance of continuing programs to instrument OCS locations in earthquake-prone areas of current interest. The program plan would include defining end-user data and analysis requirements, existing instrumentation capabilities and experience, and identifying candidate areas for field instrumentation sites and their corresponding environmental and geologic conditions. Industry and academic communities would be utilized. Specifically:

(1) Instrumentation. Develop improved systems for measuring earthquake ground motions at and below the sea bottom up to the limit of the OCS. Objectives should include improved reliability and field life and low installation, retrieval, and maintenance cost. Combination and earthquake measurement stations with oceanographic/meteorological measurement stations may prove desirable.

(2) Data Collection. Implement a long-term program to install and maintain systems to measure the selected variables in offshore and adjacent onshore areas of current and future development interest.

(3) Data Dissemination. Initiate and maintain a plan for the processing and dissemination of measured earthquake motion data to end users in government, industry, and academic communities.

The end product will be a systematic source of earthquake ground motion data from offshore and nearshore land instrumentation sites.

Oil Completion and Production

Industry Description

Offshore oil and gas is produced by means of fixed platforms, which are large, unique structures permanently attached to the ocean floor. As oil men moved into deeper waters the old pipe-truss "Texas Towers" became bigger, and heavier, and costs increased exponentially. Economic feasibility studies indicated a maximum depth of fixed structures to 180 meters of water. However, recent innovative designs indicate that these structures can be and are used in 300 meters of water. In the meantime, new concepts in platforms and great success with subsea drilling and production systems indicate that we can produce and control wells in 600 meters of sea water in exposed ocean sites. We already have the capability to drill in 1500 meters of water and greater depth, using dynamically positioned drilling platforms.[10]

Subsea completion is a phrase that describes the establishment of production from a well while leaving the wellhead and all other primary controls either exposed to the water or fully enclosed in a capsule on the ocean floor. An important advantage of subsea completion is that an oil field can be produced in deep waters where erection of platforms is too expensive, time-consuming and sometimes politically undesirable. Subsea completion in the free world's areas will increase from about \$65 million in 1977 to as much as \$250 million a year by 1985.[12]

State of the Art

The development of new production systems using a number of articulated columns, guyed towers, and tensioned buoyant platforms has progressed at a lower rate than predicted. This has been the result of a number of factors such as recent advances in the design of fixed platforms and a desire to cling to proven technologies, a slowdown in drilling programs in deeper waters, and the fact that early estimates regarding the cost and technical simplicity of the new systems were unduly optimistic.[9] Considerable progress has been made by Exxon with their "Guyed Tower" design followed by a three-year test of a 1/5th-scale model installed in 90 meters of water. Exxon states that this design will extend the water depth limits for bottom-supported drilling and production platforms to 600 meters.[11] This design and other promising tethered/tensioned buoyant platforms coupled to subsea completions and production system developments should provide the capability required in the next five years. The use of subsea completions in the future will become more commonplace since the technology and economics of subsea production are here.

Company Names

FMC Corporation, Houston
Cameron Iron Work, Houston
Schlumberger Well Service, Houston
Halliburton Services, Duncan, Oklahoma
Exxon Production Research Company
J. Ray McDermott
Brown & Root
Sohio/British Petroleum
Lockheed Petroleum Services
Gulf Oil

Problem Areas

- Maintenance of structures, wells and related equipment
- Corrosive environment and marine growth
- Protection of platforms, wellheads and pipelines from ice impact and scour in arctic regions

- Internal corrosion and erosion of wells, valves and equipment by corrosive fluids and sand inclusions in the fluids
- Data and information transmission for remote control of wells
- Deep water mooring
- Lack of data on the corrosive environment in deep water
- Lack of adequate data on the fatigue lives of structures in the marine environment.

Examples of Key Problems Amenable to High Technology Solution

With the emphasis on subsea completion systems in the future, particularly in deeper water, most of the problem areas listed above are important and will require high technology solutions. Since subsea completion systems are remote, accurate information concerning location, operating status, and maintenance problems or malfunctions is very important. The transmission and processing of this vast amount of information is a key problem area requiring high technology solutions.

Soil-Structure Interaction Under Cyclic and Dynamic Loadings.[14] Considerable attention has been given in the past 30 years to the response of foundations of marine structures to vertical and lateral loadings. For the most part this attention has used state-of-the-art design practices that are tuned for land-type structures under static and pseudo-static loadings. Limited investigations have been made of cyclic and dynamic loadings on marine foundations.

The soils comprising the thick sediments above the Atlantic continental shelf represent the potential foundation of many types of structures, including large concrete and steel bodies seated upon the sea bottom, as well as large cylindrical pipes or caissons driven into the seabed to carry axial tension and compression loads and lateral loads. A study is needed to provide answers to questions of the following types. Under the cylic loading produced by horizontal and vertical components of constantly varying wave pressure, how do the soils respond? What is the pore-pressure buildup and dissipation during cyclic loading? Is soil strength increased or diminished by the oscillations? This study should also consider the change in the soil properties caused by movements of the foundation elements considering installation procedures and subsequent

loadings; and should address factors of safety for the total structure as contrasted to factors of safety of the individual foundation elements. Increasing our knowledge of soil response to cyclic and dynamic loading will yield more reliable design and performance of bottom-seated structures at a lower capital and maintenance cost.

Offshore Pipelines

Industry Description

The offshore oil and gas pipeline industry consists of three major segments: the natural gas pipeline companies and joint ventures, which design and operate the pipeline systems; the offshore construction contractors which lay the pipelines; and other ocean engineering contractors which provide underwater inspection and repair services. Major U.S. firms involved in marine pipeline activities are shown in Table 2. Many of these firms or their subsidiaries operate worldwide.

State of the Art

The marine pipeline industry has kept pace with the offshore production trends of the 1970's, including the trends towards deeper waters and more hostile environments. The Gulf of Mexico, with more than 600 miles (1,000 km) of pipeline construction planned in 1979, continues to be a very active geographic area.[15] Two Gulf pipeline projects are of special significance: the pipeline connecting the Cognac platform to an onshore terminal in Mississippi, which set a Gulf depth record of 300 meters; and the LOOP project which will set a new Gulf pipeline diameter record of 1.2 meters (48 inches).

Worldwide, new developments are even more dramatic. The Sicilian Channel pipeline being installed by Saipem of Italy will be twice as deep as the Cognac pipeline, reaching about 600 meters in depth. In Canada, the ambitious Polar Gas Project is designing an Arctic pipeline system which would have to withstand stressful environmental conditions such as ice scour

TABLE 2. EXAMPLES OF U.S. MARINE PIPELINE FIRMS

Pipeline Operators

Natural Gas Pipeline Companies

- United Gas Pipe Line
- Transco Exploration
- Tennessee Gas Pipeline
- Transcontinental Gas Pipe Line
- Trunkline Gas
- Texas Gas
- Texas Eastern Transmission
- Southern Natural Gas
- Northern Natural Gas
- Natural Gas Pipeline
- Michigan Wisconsin Pipeline
- Columbia Gulf Transmission
- Florida Gas Transmission

Joint Ventures

- Polar Gas
- Sea Robin Pipeline
- High Island Offshore Services
- Seagull Pipeline
- Blue Water System

Others

- Shell Development
- Gulf Oil Exploration and Production
- Exxon Production Research
- Phillips Petroleum

Pipeline Construction Contractors

- Brown and Root
- McDermott Pipeline
- Sante Fe

Inspection/Repair Service Contractors

- Chicago Bridge and Iron
- Hydrotech
- International Underwater Contractors
- Oceaneering
- Global Marine Development

in channel crossings between islands. The rapid technological advances of the marine pipeline industry are reflected in the technology of the new semisubmersible pipeline ships, with high pipe tensioning capabilities, submerged pipe support, and dynamic positioning systems which allow for laying large diameter pipe in deeper waters than previously thought possible. Research is progressing to develop variable density, lighter-weight pipes, with the hope that depth records can continue to be set utilizing existing pipelaying technology.[16]

Problem Areas

The technological challenges facing the pipeline industry as it moves into deeper waters and more severe climatic environments relate to design optimization and hazard asss

ment. Present industry R&D efforts include development of variable density pipes which can withstand environmental stresses on the seafloor, as well as the combined loads -- bending, axial tension, and external pressure -- the pipe undergoes during the laying operations. In addition to environmental seafloor data (hydrofaction effects of storm waves, currents, pressure, temperature, etc.), the industry needs boundary layer data (soil stability, mudslide hazard, shear strength, etc.) for use in design optimization (pipeline routing, pipe material and dimensions, burial method). In the Artic regions, such as the Beaufort Sea, there is the additional need for sea ice data so that pipeline design can provide protection against ice scour.

Other Problems

- Inspection - need devices for measurement of internal corrosion in platform risers
- Pipeline burial techniques - selection methodology based on soils data and charts with indications of relative burial characteristics
- Long-distance pipeline design (pipe materials and configurations, pumping systems, fluid additives) for dredge transport offshore
- Evaluation of feasibility of defining pipe laying corridors through the coastal zones.

Examples of Key Problems Amenable to High Technology Solution

Typical Area Research and Survey Specifications for Offshore Corridors and Special Purposes[14]. It has been suggested that users of offshore resources (including but not limited to oil and gas drillers, pipe-layers, cable-layers, dredgers, dumpers, and miners) be confined to corridors or zones specifically located for these purposes. In order to properly zone for such uses, and to manage the corridors or zones after their establishment, numerous environmental factors must be understood, and research and survey activities conducted, always keeping in mind that the offshore is highly dynamic, constantly seeking an equilibrium which is never achieved, and that the fluxes of mass, momentum and heat are constantly moving into and out of any corridor or zone that might be selected. Accordingly, a study is needed to precisely define offshore corridors and zones, using microbathymetry techniques. A combination of sonar and side-scan surveys must be conducted along projected high-use corridors and zones. Corridor limits would be approximately five miles wide and extend from shallow water out to the toe of the continental slope. The thickness of unconsolidated sediments must be determined along corridors and zones; this can be accomplished using subbottom seismic profiling. The nature of the sediments, bearing strength, and stability must also be known (through seismic profiling). Ground truth for the microbathymetry must be obtained as a check on the mapping accuracy and on the nature of the uppermost layer of sediment; here, in-situ observation with manned submersibles is in order. The wave climate and currents must be understood, and the storm regime must be known; if these data are not available, they must be gathered over a period of at least a year. Finally, to be acceptable, the impact of such corridors or zones on onshore populations and their economics must be studied and agreed to by all concerned. It follows that research in the sociopolitical arena will be required.

Definitive Studies on Geotechnical Properties and Behavior of Marine Soils.[14] Investigations and research in dynamic properties of soils as related to marine structures have been initiated by industry, consultants, educational groups, and governmental agencies; but additional efforts are needed in view of the importance of dynamic soil properties in the total assessment of integrity of marine foundations. There is a need for a basic understanding of those engineering properties of marine soils that can be studied in isolation. A comprehensive program is needed in this area; it should include theoretical analysis, in-situ test procedures and instrumentation, improved core sampling techniques, and laboratory testing. The proposed research and development effort should focus on:

(a) Development of improved core sampling equipment and techniques to provide relatively undisturbed soil samples for laboratory testing and better understanding of factors which influence soil properties.

(b) Research to improve the understanding of engineering properties of marine soils such as creep strength, short-term shear strength, damping, change in strength and material properties under dynamic and static loading, compressibility, and strength-effective stress relationships.

(c) Development of comprehensive laboratory and in-situ instrumentation and standardized techniques for determining realistic dynamic and static response.

OCEAN ENERGY CONVERSION

Industry Description

Ocean thermal energy conversion was first attempted in the late 1920's with a small demonstration plant. Even though the system produced energy, very little progress has been made until recent years. This process depends on the temperature differential between low-temperature bottom waters and high-temperature surface waters for employment of heat engines to extract energy from the oceans. Since the efficiency of such systems depends on the temperature differential,

such systems would only be feasible in tropical waters, or in some cases, more northern or southern waters if placed in ocean rivers such as the Gulf Stream, which maintains a high differential throughout the world. Since this concept requires a huge amount of research, development and capital investments, industry has been reluctant to put any large sums of money in this area. Therefore, the U.S. government has been financing practically all of the prototype and critical component development work under the Department of Energy (DOE) which had a FY-78 budget of $35 million for this program. Although most of the funding was for OTEC research, new programs investigating other ocean energy sources--waves, tides, currents, salinity gradients--were begun.

State of the Art

Ocean thermal energy conversion is in the pilot development stage, where technical feasibility is assured but economical feasibility is questionable. The large developmental and research costs coupled with high capital investment requirements have led to government sponsorship and funding of most of the advances in this area. Currently, a 50-kw "Mini-OTEC" plant has been deployed off Hawaii by a consortium of Lockheed, Rotoflow, Delaval, and others. Operation of this plant was scheduled to start in June 1979. The DOE-sponsored pilot plant OTEC-1, a 1-megawatt plant, will be installed in a converted oil tanker, which is scheduled to be in operation off Hawaii in late 1979. The prime contractor for this program is Global Marine Development, Inc. Two large pilot plants in the 10 to 40-megawatt range are currently being designed under the sponsorship of the DOE.

Other ocean energy devices are being evaluated by the United Kingdom, France, and Japan. Lockheed has developed and patented an ocean wave energy device (2 megawatts) which has only one moving part and which does not require energy conversion. The unit consists of a 75-meter concrete dome, which is installed submerged, and topped by guide vanes which spiral incoming waves into a vortex, producing energy which the unit consumes, creating calm waters ideal for beach protection.

Company Names

Lockheed Marine
TRW
Global Marine Development, Inc.
M. R. Rosenblatt & Sons
Brown & Root
Gibbs & Cox

Problem Areas

Critical problem areas remain. The most significant of these are now:

1. Heat Exchanger Problems
   a. Thermal Design
   b. Biofouling
2. Ocean Engineering (in order of increasing difficulty)
   a. Platform
   b. Mooring
   c. Power Cable
   d. Cold Water Pipe (CWP).

Satisfactory heat transfer coefficients have been achieved by the various heat exchanger designs tested so far. Of far greater immediate significance is the problem of biofouling. It is presently expected that cleaning using a mechanical method (AMERTAP) will prove effective. Sea trials on OTEC-1 may resolve this question.

The problems related to ocean engineering are perhaps the most significant at the present time. Power cables must be designed to sustain the combined electro/mechanical loading induced in a 40-megawatt (400-megawatt in commercial plants) cable by electrical current and hydrodynamic loads over a 915-meter (minimum) span. The problems of mooring the platform are presently regarded as being within the state of the art. (Mooring questions are presently being investigated by M. R. Rosenblatt & Sons, Inc.)

Similarly, the problems of platform (ship, spar, etc.) design and construction are regarded as being well within the state of the art.

The cold water pipe presents severe engineering challenges. Conceive of a pipe 30 meters in diameter and 915 meters long. This is what will be required for a commercial plant. Approximately ten designs, including a variety of materials and geometries, have been identified. Two groups of contractors have been performing engineering/economic studies of the various concepts. Alternative concepts (guyed towers, tension leg platforms, and articulated towers) from the oil industry have been considered and were proposed at the ocean-engineering workshop during the OTC conference in 1979.

Other Problems

- Need wave data and analysis techniques for evaluating feasibility of ocean wave energy devices, and eventually for site selection and mooring load analyses.
- Need more information on deleterious effects (corrosion, fatigue, fouling, impact loading, etc.) of marine environment on offshore structures.

SUPPORTING INDUSTRIES

Ocean Bottom Surveys

Industry Description

This is a service industry composed of three segements: the marine geophysical surveying service contractors, the equipment suppliers, and the vessel suppliers. The service contractors supply services to customers, such as petroleum firms, and various in-house capabilities such as owning or leasing geophysical survey vessels, manufacturing/buying/leasing survey equipment. Examples of firms composing the three industry segments are shown in Table 3.

This is a complex, continuously changing industry, which is characterized by small specialized firms; larger, more diversified firms; and subsidiaries of large corporations, such as Texas Instruments, Litton and Raytheon. A detailed description of this industry is beyond the scope of this

TABLE 3. EXAMPLES OF OCEAN BOTTOM SURVEY FIRMS

Marine Survey/Exploration Service Contractors

- * Digicon Geophysical Corp., Houston
- * Geophysical Service, Inc./Texas Instruments, Dallas
- * Petty-Ray Geophysical, Inc., Houston
- * Western Geophysical Co., Houston
- * Teledyne Exploration Co., Houston
- * Tracor Marine, Inc., Ocean Technology Division, Port Everglades, Florida
- * Esso Seismic, Inc.
- * Shell Oil
- * Mobil Oil
- Continental Oil
- EG&G, Inc., Waltham, MA
- Klein Associates, Inc., Salem, NH
- Hydro Products/Tetra Tech, San Diego
- Offshore Navigation, Inc., Harahan, LA
- Raytheon Submarine Signal Division, Portsmouth, RI
- Seiscom Delta Inc., Houston

Equipment Suppliers

- EG&G Geophysical Ltd., U.K.
- Edo Western Corp., Salt Lake City, Utah
- Environmental Devices Corp., Marion, MA
- General Instrument Corp., Harris Lab., Westwood, MA
- Geo Metrics, Inc., Sunnyvale, CA
- Offshore Navigation, Inc. ,LA
- Raytheon Marine Co., Manchester, NH

* In-house vessel capabilities, fully equipped.

study, but should be pursued under a separate effort if technology transfer to this industry is being considered. Of particular interest would be determination of industry leaders of the data collection and the data processing technologies, since the commercial geophysical surveying/exploration systems are considerably ahead of the academic capabilities in terms of advanced technology.

The basic services supplied by the ocean bottom surveying industry, in support of petroleum exploration, offshore construction, pipeline/cable laying, and offshore mining operations, are: (1) geophysical surveying (seismic, magnetic, gravity, and borehole measurements); (2) hydrographic/bathymetric mapping of ocean floor topography (hazards, routing, etc.); and (3) core sampling and soil/mineral assaying. Firms that provide these services in support of the petroleum, pipelaying, and mining industries must either own or charter a geophysical survey vessel, which costs $3 million or more; plus equip, or rent a fully equipped vessel (an additional investment of up to $1 million), and must invest large amounts in staffing data processing centers, with expensive hardware, software, and highly paid technicians.

Worldwide, expenditures on marine seismic surveying activities associated with petroleum exploration (the major market for seismic services) exceeded $200 million in 1978. In the U.S., the expenditures for petroleum seismic activities in the marine environment totaled almost $77 million, of which $58 million was for activities in the Gulf of Mexico.[17]

Another geophysical activity increasing in importance is gravity/magnetic surveying. U.S. expenditures for gravity and magnetic surveys in support of petroleum exploration totaled almost $3.5 million in 1978, up 67% over 1977. Expenditures for gravity and magnetic surveying in support of other exploration--minerals, geothermal, ground water, research and engineering--totaled an additional $3 million in 1978.[17]

State of the Art

Ocean bottom exploratory activities are undertaken to (1) locate geological formations which are potential oil and gas reservoirs, (2) determine the topography of the sea floor for mapping/charting of navigation hazards, and (3) define the properties of the ocean bottom soil that provides

the foundation for establishing large structures and dumping sites, and laying cables and pipelines. Prerequisite to these survey activities is accurate positioning information, both at the ocean surface and on the ocean bottom.

Recent technological advances in this industry include: three-dimensional scanning, color graphic displays, improved resolution and accuracy, and a new generation of minicomputer data processing systems, capable of obtaining more and better quality information from collected data, through advances in number of channels and number of bits per datum.

The offshore geophysical industry is quite sophisticated in the development of advanced techniques and instrumentation and in signal processing. Both government and academic institutions are far behind in this area. The state of art in seismic surveying is multichannel reflection seismic surveying, in which commercial systems are presently more advanced than academic systems. Indeed, the U.S. leads the world in this technology. Currently, 48 and 96 channel systems are used in seismic surveys.[20] Higher channels are also being displayed and used. The increased number of channels is employed successfully to provide redundancy and cancel random noise. Also, spacing between detectors is made to discriminate against horizontal waves and to receive the returns from waves propagating downward. New advanced techniques generating vibrating signals were developed for land and are being applied at sea. They can generate a known signal (linearly swept frequency like a chirp, starts at 10 Hz and goes to about 80 Hz). A generated signal, seven seconds long, is used to scan the above range of frequencies. The industry is also most sophisticated in signal processing. All recordings are made digitally to maintain the dynamic range and also for ease in filtering and computer processing. But, seismic data collection technology may stagnate if new areas of petroleum exploration, such as frontier areas in the offshore continental shelf (OCS), are not available for future leasing due to restricted federal policy.

The bathymetric/hydrographic techniques used today in ocean bottom topographic surveys produce levels of accuracy and resolution that would have been unthinkable only a few years ago.[18] It therefore follows that even tighter tolerances will be the order of the day in the not too distant future. Hydrographic survey services fall into two categories: surface systems and submersible systems. Submersibles currently are in great demand because

increased accuracy and resolution require that survey sensors be located as close as possible to the ocean floor. Long-endurance survey submersibles today carry advanced-design electronic equipment that has brought subsea surveying to a point where in some respects it can be compared quite favorably with precision land surveying.

The development of offshore areas necessarily involves the emplacement of many types of marine structures in the continental shelf and slope. Such structures include offshore drilling platforms, pipelines, cables, waste disposal outfalls, and structures to support navigation aids; and all of these structures must be supported by the seafloor.[10] Core/soil sampling techniques are being used today to determine seafloor soil properties and structure. A need exists for a better understanding of the geotechnical properties and behavior of marine soils and of the interaction of soils with structures. Perhaps a first step was taken in obtaining this understanding when a preliminary research plan was generated and distributed to practitioners in industry, academia and government during a major study conducted recently on seafloor engineering needs.[19]

High technology is clearly the order of the day for electronic equipment used for subsea mapping; and not only for equipment installed on the submersible, but also for that installed on the support ship from which the submersible operates. The industry now demands on-site processing of every element of data that has been collected. Vickers Oceanics Ltd. has developed its Hydroplot system as a ship installation which allows real-time operation of both ship and submersible. Very advanced sensors are available for bathymetry which, when positioned 2 meters above the seabed, produce myriad details as a result of their capability for high resolution. Used in conjunction with shallow coring techniques and sensors for subbottom profiling, they enable charts of unsurpassed detail to be produced. A current acoustic ranging system permits underwater measurements to an accuracy of $\pm$ 5 cm in 100 meters.[18] Acoustic tracking techniques are still favored by the industry for determining the submersible's position, but there is a gradual move toward Doppler systems, which are especially useful for operations in the vicinity of platforms.

The technology in seafloor soil mechanics and foundation engineering is reaching a state of maturity that will allow most of the typical engineering problems to either be accommodated in design, or avoided; however, a large amount of work remains to be done in applying seafloor geotechnical information

to nontypical needs associated with supporting structures and with operating equipment on the ocean bottom.[19] The capability to obtain reliable cores of deep ocean sediments to depths of at least 30 feet is currently available, although much work has been done during the past two decades to obtain samples of good engineering quality. Undersea work systems are presently being considered for use in the protection of cables and pipeline in the surfzone and in the burial of seafloor cables in the deep ocean. Recent developments in acoustic measurement of geotechnical properties are being reviewed to determine the potential improvements possible in present geophysical exploration techniques as applied to engineering needs.[19]

Problem Areas

- New devices and techniques for mapping the ocean bottom with greater accuracy and at lower cost than present systems.[4]
- Behavior of the seafloor under variable loadings and on slopes.[14]
- Survey of continental margin and development of high-resolution bathymetrics.[14]
- New instruments for navigation and positioning.[14]
- Buoy system to facilitate precise locations and routing within 200-mile zone.[14]
- Effective positioning systems for maintaining large ocean platforms on station.[4]
- Soils data and oceanographic and meteorologic data for the U. S. Atlantic continental shelf.[14]
- Effect of the bottom boundary layer on offshore processes.[14]
- Improved soil sampling techniques to minimize sample disturbance and improved procedures for the quantitative assessment of sample disturbance and its causes.[19]
- Measurement offshore of both microseismic activity and strong motion activity in areas of concern.[19]

- Improved sediment transport predictions on the continental shelf.[14]
- Geophysical and remote sensing techniques for site characterization: definition of soil types, their geometrical boundaries, and their goetechnical properties.[19]
- Structural responses of platforms and underwater structures to earthquake forces.[4]
- Practical bottom-mounted and subbottom long-life markers for OCS lease benchmarking and shut-in well marking.[4]
- Feasibility study on using a submarine to determine the nature of the under-ice ocean environment and the petroleum resource potential of the Arctic ocean areas.[4]
- Complete reconnaissance inventory and assessment of the mineral resources available to the U. S. on its continental shelves.[4]

<u>Examples of Key Problems Amenable to High Technology Solution</u>

Since this is a service industry, the technological problems noted above are problems affecting the operations of primary marine industries, such as offshore oil/gas exploration and production, marine pipe/cable laying, and deep ocean mining. Thus, although improvements in technology are supplied through R&D efforts of this service industry, the demand (i.e., need) for technological improvements is generated in the primary industries, which pay the service industry to supply needed technology and technical expertise. For this reason, high technology solutions listed below are discussed within the industry subsection* to which they most apply:

Needed Technological Improvements	Industry
Soil-Structure Interaction under Cyclic and Dynamic Loadings	* Oil Completion/Production - Offshore Pipeline
Definitive Studies on Geotechnical Properties/ Behavior of Marine Soils	* Offshore Pipeline - Oil Completion/Production - Deepsea Mining
Typical Area Research and Survey Specifications for Offshore Corridors/Zones	* Offshore Pipeline
Earthquake Measurement Programs	* Offshore Platforms - Oil Completion/Production

Additionally, there is one problem area amenable to high technology solution which is needed, perhaps to a varying degree, by all marine industries discussed in this study.

Nautical Charting of the Outer Continental Shelf.(4) A base needs to be established for production of a national hydrographic plan and policy statement. This would provide direction for product design and development to support other than surface marine transportation requirements of the public sector, and would place support for economic development of the oceans in a more realistically competitive position to receive federal funds. Therefore, a study is required to define in realistic terms the needs for nautical charts related to economic exploitation of the oceans and the characteristics of the chart or product that best meets that need. The sequence of steps would include:

(1) Determine specific product and area requirements, (especially scale of charts by OCS regions) for nautical charts and related products to meet the needs of current ocean operations, with particular emphasis on the OCS.

(2) Project requirements into the future and recommend priority and schedule of requirements.

(3) Establish continuing procedures for civil ocean operators to the state requirements for charts and related products.

The end product will be a consolidated statement of nautical chart and related product requirements for the civil and government user that is current, updatable, based on specific and realistically projected needs, in recommended priority order with a recommended schedule, and a forecast of proposed expenditures required.

Underwater Transportation, Data Collection and Work Systems

Industry Description

Underwater transportation in the offshore oil and gas industry has been limited to small two, three and four-man slow submersibles used for surveying pipeline routes, inspection of platform sites, pipeline systems and observing and controlling pipe laying and trenching and construction operations. Most of these submersibles are powered by electric or hydraulic motors at speeds of 2 to 4 knots. Several are fitted with manipulators, tools and instruments. Most of these are limited to depths of 300 to 600 meters of water and have limited duration. A small number are fitted with lock-out chambers to transport and recover divers to and from work sites. Most activities in this area are directed toward development of remotely controlled vehicles (RCVs) and towed vehicles (manned and unmanned) to conduct surveys, and observing operations, such as pipelaying and searches for lost equipment and other tasks. The RCVs being developed today are sophisticated vehicles equipped with lighting, cameras, television, sonars, test equipment and in some cases manipulators and tools to accomplish many tasks formerly completed by divers. An important future role for such vehicles equipped with the necessary instrumentation is to conduct geological exploration surveys to improve the efficiency of geologists in finding oil and gas. Further, these vehicles can obtain basic data on soil mechanics and investigate seismic-disturbance-prone deep ocean trenches, and underwater mudslides in areas such as the Baltimore Canyon off the Atlantic coast.

State of the Art

The rapid growth in undersea vehicles which followed the development of North Sea oil and gas discoveries of the late sixties and early seventies continues, according to R. Frank Busby.[21] While the diver still conducts most of the underwater activities, this role is decreasing dramatically as operations move into deeper waters. The role of manned submersibles, remotely controlled vehicles and one-atmosphere diving suits (1-ADS) is increasing. This increase is evident in a 1976 inventory of manned submersibles, which revealed that 91 vehicles were operational or under construction. In 1977, seventy RCVs were operational or planned (excluding military vehicles) and ten 1-ADS had been produced, with 13 more under construction.[21] Operational RCVs increased from 39 to 53 during 1978, but the number of manned submersibles showed a decrease, down by six vessels.[22]

Company Names

Martech Int.
Oceaneering Int.
Perry Submarine Builders
Vickers
Intersub
Hydroproducts, Inc.
Honeywell
Data Systems
E.G. & G.

Problem Areas

- Reliability and maintainability of instrumentation, electrical and electronic systems
- Bottom navigation and location
- Handling in heavy weather in launching and recovery operations
- Work system packages must be designed for the limited payload and stability characteristics of small vehicles
- Offshore oil and gas installations including wellheads, production and storage systems, platforms and pipelines should be designed so that the limited capabilities of manipulators and tools can be employed effectively.

Inspection and Diving Services

Industry Description

Inspection and diving services and the offshore oil and gas industry have both enjoyed rapid growth and formed the cutting edge of the state of the art in diving, diving physiology, underwater tools, underwater cutting and joining, inspection instruments and petroleum engineering. In addition, small submersibles which can lock-out and recover divers on the ocean bottom have been pushed by the needs of the offshore oil and gas industry. With increasing water depth, air diving is usually abandoned at 50 meters and helium-oxygen diving is adapted. Saturated diving is instituted at greater depths; however, the high cost of such diving in depths greater than 180 meters has forced the oil and gas industry to design systems which don't require divers, or at least minimize the need for divers. This trend has led to the development of subsea wellhead and ocean bottom production systems which can be installed, maintained and controlled without the use of divers. In addition, we have seen more growth in small two- or three-man submarines, which may be fitted out with manipulators and tools to perform inspections and limited underwater work. These submarines are usually slow, 2 to 4-knot vehicles with operating ranges limited to tens of miles and depths of 300 to 600 meters. Several have much greater depths but at this point they are in the minority.

Recently, there has been a rapid growth and variety of small unmanned submersibles, or remotely controlled vehicles. These are usually equipped with cameras, television cameras, and in some cases manipulators, tools, sonars and instruments to measure corrosion potentials on pipelines, wellheads and structures. These vehicles are taking over the role of divers in many offshore applications, such as survey and inspection of pipeline routes, inspection for leaks and deterioration of pipelines and platform structures. However, most of the RCVs use cables

to provide power, and transmit data and information to the control station; these cables limit the usefulness of these vehicles to inspect traditional tower-type platforms because of cable fouling, especially for inspecting internal structural members. The lack of adequate nondestructive testing procedures and instruments has plagued the efficiency of diver inspections, but the situation is much more difficult with low-powered cumbersome vehicles. This problem area is covered in detail by R. Frank Busby.(23) This industry will gross an estimated $60 to 70 million in 1979.(24)

State of the Art

Diving in support of oil and gas exploration and drilling in water depths over 200 meters is in its infancy.(11) A limited number of diving contractors have the mixed gas capabilities for deeper diving. One company completed a 1050-ft (315-meter) open-water demonstration dive in February 1978. Simulated dives in hyperbaric chambers have provided enough data and procedures to enable that company to anticipate that 450 meters is technically feasible. However, the long decompression periods and the economics of such deep dives are forcing contractors to design offshore systems to eliminate or limit the need for divers.(24) Remotely controlled vehicles, manned an unmanned submersibles, diving bells and one-atmosphere working systems are being developed to replace divers in deep water operations. Some smaller RCVs have been found to be cost-effective in jobs of 150 meters and less.(25)

Company Names

Oceaneering International, Inc., Santa Barbara
Martech International, Houston
International Underwater Contractors, Inc., New York
Taylor Divers, Morgan City, LA
Santa Fe Diving Services, Inc., Houma, LA
J&J Marine Diving Company, Pasadena, TX
Murphy Pacific, San Francisco
Crowley Marine, Seattle.

Problem Areas

- High costs of mixed-gas and saturated diving
- Physiological problems related to bone necrosis, the physiological performance of women divers and the effects of high pressure on pregnancy, sickle-cell anemia and drug use.
- The need for a reliable means to determine structural integrity of structures, such as crack detection and the extent of deterioration without removal of marine growth.
- Tools, equipment, wellheads, pipelines and structures require designs which can facilitate the limited capabilities of divers, manipulators and other work systems.
- Development of RCVs without the use of cables, and a means for data transmission.

The last three problems may be amenable to high technology system-type solutions.

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